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COMBUSTOR EXHAUST EMISSIONS WITH
AIR-ATOMIZING SPLASH-GROOVE FUEL INJECTORS
BURNING JET A AND DIESEL NUMBER 2 FUELS

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16. Abstract Air-atomizing splash-groove injectors, utilizing fuel jets impinging against a grooved face, gave improved primary-zone fuel spreading and reduced combustor exhaust emissions for Jet A and diesel number 2 fuels. Test conditions included fuel-air ratios of 0.008 to 0.018, inlet-air pressures of 41 to 203 N/cm ² , inlet-air temperatures of 477 to 811 K, and a reference velocity of 21.3 m/sec. With Jet A fuel large-orifice splash-groove injectors reduced the oxides-of-nitrogen emission index to 15, a value 25 percent less than that for previously tested air-atomizing splash-cone nozzles, but did not reduce emissions of carbon monoxide, unburned hydrocarbons, or smoke (at 700 K, 203 N/cm ² , and an 0.018 fuel-air ratio). Small-orifice splash-groove injectors did not reduce oxides of nitrogen but reduced the smoke number to 11, or by 45 percent (at 700 K, 101 N/cm ² , and an 0.018 fuel-air ratio) and reduced carbon monoxide and unburned-hydrocarbon emission indices to 35 and 12, or by 20 and 30 percent, respectively (at 477 K, 41 N/cm ² , and an 0.008 fuel-air ratio). With diesel number 2 fuel, the small-orifice splash-groove injectors (compared with pressure-atomizing nozzles) reduced oxides of nitrogen by 19 percent, smoke number by 28 percent, carbon monoxide by 75 percent, and unburned hydrocarbons by 50 percent. Smoke number and unburned hydrocarbons were twice as high with diesel number 2 as with Jet A fuel. Combustor blowout limits were similar for diesel number 2 and Jet A fuels.					
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COMBUSTOR EXHAUST EMISSIONS WITH AIR-ATOMIZING SPLASH-GROOVE FUEL INJECTORS BURNING JET A AND DIESEL NUMBER 2 FUELS

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SUMMARY

Two experimental air-atomizing splash-groove injectors, utilizing fuel jets impinging against a grooved face to give improved primary-zone fuel spreading were tested for exhaust emissions in an experimental combustor using Jet A and diesel number 2 fuels. In the initial tests, with Jet A fuel, exhaust emissions were obtained for these two air-atomizing splash-groove injectors, models A and B, and results were compared with previous data obtained for air-atomizing splash-cone nozzles, which utilized fuel jets impinging on a conical face. In the final tests, with diesel number 2 fuel, exhaust emissions were obtained with splash-groove injector model B and conventional pressure-atomizing nozzles for comparison. Test conditions included fuel-air ratios of 0.008 to 0.018, inlet-air pressures of 41 to 203 newtons per square centimeter, inlet-air temperatures of 477 to 811 K, and a reference velocity of 21.3 meters per second.

The two splash-groove injector designs which were tested, models A and B, had twenty-one 0.076- and forty-two 0.051-centimeter-diameter orifices, respectively, and had similar total orifice areas and fuel pressure drops. In burning Jet A fuel, injector model A (with large orifices) did not reduce carbon monoxide, unburned hydrocarbons, or smoke but gave a reduction in the oxides-of-nitrogen emission index of nearly 25 percent (from 20 to 15) below that for either injector model B or splash-cone nozzles (at 700 K, 203 N/cm², and an 0.018 fuel-air ratio). In comparison with splash-cone nozzles, splash-groove model B (with small orifices) did not reduce oxides of nitrogen but reduced smoke number by 45 percent (from 20 to 11) (at 700 K, 101 N/cm², and an 0.018 fuel-air ratio) and reduced carbon monoxide and unburned hydrocarbons by 20 and 30 percent, respectively (at 477 K, 41 N/cm², and an 0.008 fuel-air ratio).

Smoke number and unburned hydrocarbons for diesel number 2 fuel were approximately twice those for Jet A fuel. This difference was attributed to the fact that diesel number 2 fuel has a higher concentration of aromatics and a higher boiling point. Combustor blowout limits for diesel number 2 and Jet A fuels were approximately the same.

INTRODUCTION

Two experimental air-atomizing fuel injectors with improved fuel spreading were evaluated on the basis of exhaust pollutant emissions in a combustor segment. Tests were made with Jet A and diesel number 2 fuels.

In two recent investigations (refs. 1 and 2) an air-atomizing nozzle was developed which gave a reduction of approximately 30 percent in the oxides-of-nitrogen emission index, compared with pressure-atomizing nozzles, at a simulated engine takeoff condition of 590 K and 203 newtons per square centimeter. This reduction was attributed to the fact that splash-cone nozzles effectively utilize airstream momentum in providing better atomization and spreading of the fuel spray across the combustor cross section and thereby minimize the formation of high-temperature zones, which produce high concentrations of oxides of nitrogen. Also, air-atomizing nozzles, compared with conventional pressure-atomizing nozzles, require lower fuel pressure drop, are simpler to fabricate, and are very durable at high operating temperatures (ref. 2). Because of these advantages, engine manufacturers are beginning to use air-atomizing injectors more in designing advanced turbojet engines.

In the present investigation, two air-atomizing splash-groove injectors designed for improved fuel distribution were tested for exhaust emissions, and the results were compared with those for previously tested air-atomizing and pressure-atomizing nozzles. The injectors were designated models A and B and had twenty-one 0.076- and forty-two 0.051-centimeter-diameter orifices, respectively. Injector model B and pressure-atomizing nozzles were used to test for exhaust emissions from burning diesel number 2 fuel for comparison with Jet A fuel. Also, combustor blowout conditions were determined for diesel number 2 and Jet A fuels. Test conditions included fuel-air ratios of 0.008 to 0.018, inlet-air total pressures of 41 to 203 newtons per square centimeter, inlet-air temperatures of 477 to 811 K, and a reference velocity of 21.3 meters per second.

APPARATUS AND PROCEDURE

The experimental combustor was mounted in the closed-duct test facility shown in figure 1. In figure 2, the combustor is shown with a splash-groove fuel injector installed at the inlet to the primary zone. Descriptions of the test facility, test combustor, and instrumentation are given in appendix A. Procedures for measuring gaseous exhaust emissions and smoke samples and for calculating smoke number are described in appendix B.

The fuel injector tested, shown in figure 3(a), was an air-atomizing splash-groove injector designed to improve the uniformity of fuel distribution in the combustor primary

zone. Test injectors were mounted in combustor snouts as shown in figure 3(b). Injector performance was evaluated primarily on the basis of emission characteristics of the combustor. Models depicting fuel flow and airflow around the splash-groove nozzle of this report and the splash-cone air atomizing nozzle of reference 1 are shown for comparison in figure 4. The splash-groove design more evenly distributes the fuel closer to the flame stabilizer and more directly into the recirculation zone. Obtaining a more uniform distribution of fuel and burning at leaner mixtures across the primary zone should be beneficial in reducing oxides-of-nitrogen emissions. Also, injecting fuel closer to the flame stabilizer should be beneficial in reducing carbon monoxide and unburned-hydrocarbon emissions.

Splash-groove injector model A, shown in figure 3(a), contained twenty-one 0.076-centimeter-diameter orifices and was used only with Jet A fuel. The same splash-groove design was used for injector model B except that it contained forty-two 0.051-centimeter-diameter orifices and was used with Jet A and diesel number 2 fuels. The two injectors had similar total orifice areas and fuel pressure drops. The simplex pressure-atomizing nozzle, shown in figure 5, was used only with diesel number 2 fuel. Splash-cone nozzles were not tested in the present study.

Physical and chemical properties of Jet A and diesel number 2 fuels are given in table I. Variations in fuel flow rate with pressure drop are given in table II for splash-groove injector models A and B and the pressure-atomizing nozzle, which were the only fuel injectors tested in this study. The higher pressure drop obtained with diesel number 2 fuel was attributed to its higher viscosity (table I).

RESULTS AND DISCUSSION

Splash-groove injector models A and B were evaluated for exhaust emissions with Jet A fuel. Diesel number 2 fuel was burned with injector model B and pressure-atomizing nozzles for comparison. The fuels were burned at fuel-air ratios of 0.008 to 0.018, a reference velocity of 21.3 meters per second, and the combustor inlet-air conditions given in table III. Oxides-of-nitrogen emissions and smoke number were evaluated primarily at simulated engine takeoff conditions of 700 K, 203 and 101 newtons per square centimeter, and an 0.018 fuel-air ratio. Emissions of carbon monoxide and unburned hydrocarbons were evaluated primarily at simulated engine idle conditions of 477 K, 41 newtons per square centimeter, and an 0.008 fuel-air ratio. Also, combustor blowout conditions were determined for diesel number 2 and Jet A fuels.

Exhaust Emissions With Jet A Fuel

Emission indices for oxides of nitrogen (NO_x , expressed in terms of NO_2), carbon monoxide (CO), and unburned hydrocarbons (CH_2) and smoke number were determined for splash-groove fuel injector models A and B, and the results were compared with values for splash-cone nozzles reported in reference 2.

Effect of inlet-air temperature on exhaust emissions. - The increase of NO_x emission index with increasing inlet-air temperature, at a fuel-air ratio of 0.018 and an inlet-air pressure of 41 newtons per square centimeter, is shown in figure 6(a). Splash-groove injector model A consistently gave NO_x values below those of injector model B and the splash-cone nozzle, which were nearly the same. The higher penetration of the larger drops produced by the larger orifices in injector model A appeared beneficial in spreading out the flame front in the primary zone and thereby producing lower NO_x emissions.

Splash-groove injector model B, with small orifices, gave the lowest CO emission indices, as shown in figure 6(b). At 477 K, the CO value was 36, compared with 45 for the splash-cone nozzle, or approximately 20 percent less. A value of 58 was obtained with injector model A. This higher value was attributed to the larger fuel jets and the larger drops which they produced. It indicates the desirability of using small orifices (model B) to obtain low CO emissions.

As shown in figure 6(c), injector model B, with small orifices, gave the lowest unburned-hydrocarbon emission indices. At 477 K, the value was 12, compared with 17 for the splash-cone nozzle, or approximately 30 percent less. Injector model A gave a higher value of 35. Thus, decreasing drop size reduced unburned-hydrocarbon emissions.

Effect of inlet-air pressure on oxides-of-nitrogen emissions. - The increase in NO_x emission index with increasing inlet-air pressure is shown in figure 7. Injector model A, with large orifices, gave a NO_x value of approximately 15, at 700 K and 200 newtons per square centimeter, compared with 20 for the splash-cone nozzle, for a reduction of nearly 25 percent. Values for injector model B and the splash-cone nozzle were approximately the same. The reduction in NO_x obtained with injector model A, which produced larger drops that penetrated farther into the airstream, indicates that, for the splash-groove injector, an optimum drop size may exist for producing a minimum in NO_x emissions.

Effect of fuel-air ratio on exhaust smoke number. - Smoke numbers increased with increasing fuel-air ratio, as shown in figure 8. The lowest smoke numbers were obtained with injector model B. The small orifices appeared beneficial in producing low smoke numbers, just as they reduced CO and unburned-hydrocarbon emissions. At a fuel-air ratio of 0.018, injector model B, compared with the splash-cone nozzle, gave a smoke-number reduction of approximately 45 percent, from 20 to 11.

Exhaust Emissions With Diesel Number 2 Fuel

Emission indices for NO_x , CO, and unburned hydrocarbons and smoke numbers were obtained with splash-groove injector model B and the pressure-atomizing nozzle using diesel number 2 fuel. No data were available for splash-cone nozzles.

Effect of inlet-air temperature on exhaust emissions. - The increase in NO_x values with increasing inlet-air temperature is shown in figure 9(a). At 41 newtons per square centimeter and 800 K, the pressure-atomizing nozzle with diesel number 2 fuel gave a NO_x value of 16, compared with 18.5 for injector model B. However, at high combustor pressure, as discussed in the next section, NO_x emissions were lower with injector model B. Tests were not made with injector model A using diesel number 2 fuel, but this injector would be expected to give NO_x values close to values for the pressure-atomizing nozzle, as indicated by results obtained with Jet A fuel. Figure 9(a) includes NO_x values from figure 6(a) for injector model B using Jet A fuel for comparison; NO_x values were higher for diesel number 2 fuel than for Jet A fuel. This difference could not be explained from data on fuel properties in table I.

At 500 K, as shown in figure 9(b), the CO emission index was 25 for injector model B, compared with 100 for the pressure-atomizing nozzle. This difference represented a 75-percent reduction in CO. Also, the CO value was approximately the same for diesel number 2 and Jet A fuels with injector model B.

Unburned hydrocarbons were also significantly reduced with injector model B, from 58 for the pressure-atomizing nozzle to 28 (at 480 K), as shown in figure 9(c), for a reduction of approximately 50 percent. However, the unburned-hydrocarbon value of 28 for diesel number 2 fuel was considerably above the value of 12 obtained for Jet A fuel with injector model B. This was attributed to the higher boiling-point constituents in diesel number 2 fuel (table I).

Effect of inlet-air pressure on oxides-of-nitrogen emissions. - As shown in figure 10, at 700 K the pressure-atomizing nozzle gave a much higher increase in NO_x emission index with increasing pressure than injector model B. At 200 newtons per square centimeter, the NO_x emission index was lowered by using injector model B, from 21 for the pressure-atomizing nozzle to 17, for a reduction of approximately 19 percent. Also, the NO_x value was lower for diesel number 2 fuel than for Jet A fuel at 200 newtons per square centimeter with injector model B. This result was attributed to the higher viscosity of diesel number 2 fuel (table I), which produced larger drops that penetrated farther into the high-density airstream and thereby spread the flame and reduced NO_x emissions. Thus, factors which influence drop size and penetration such as fuel viscosity and injector orifice diameter are important criteria to be used in designing a fuel injector for low NO_x emissions.

Effect of fuel-air ratio on exhaust smoke number. - At a fuel-air ratio of 0.018, as shown in figure 11, the smoke number of 28 for the pressure-atomizing nozzle was

reduced to 20 with injector model B, or approximately 28 percent, by using diesel number 2 fuel. However, with injector model B, the value of 20 for diesel number 2 fuel was considerably above the value of 11 obtained with Jet A fuel. This difference was attributed to the lower percentage of hydrogen and the higher concentration of aromatics in diesel number 2 fuel. Smoke number could possibly be improved further by reducing the orifice diameter used for injector model B and increasing the number of orifices to keep the same fuel pressure drop.

Blowout Tests With Diesel Number 2 and Jet A Fuels

The minimum inlet-air total pressure at which steady combustion could be maintained in the combustor by using Jet A and diesel number 2 fuels with splash-groove injector model B is shown in figure 12. Test conditions included a fuel-air ratio of 0.020, an inlet-air total temperature of 311 K, and three airflow rates. Minimum inlet-air total pressures at blowout were slightly lower for diesel number 2 fuel than for Jet A fuel. This result was unexpected since the volatility of diesel number 2 fuel is somewhat lower than that of Jet A fuel, as indicated in table I, and generally improvements in blowout and altitude relight limits are obtained with a more volatile fuel, as demonstrated in reference 3. However, data in the present study were obtained at only one inlet-air temperature (311 K). Lower inlet-air temperatures would be more useful in demonstrating the effect of fuel volatility on blowout limits. Thus, for the conditions of this study, combustor blowout limits for diesel number 2 and Jet A fuels were approximately the same.

Combustor blowout limits given in reference 1 for splash-cone injectors using Jet A fuel are included in figure 12 for comparison with those for splash-groove injector model B. At the combustor design reference velocity of 21.3 meters per second, the splash-groove nozzle gave an inlet-air pressure limit of 4.5 newtons per square centimeter, which was considerably below the value of 8 obtained in reference 1 for the splash-cone nozzle. Thus, the splash-groove nozzle showed a marked improvement in combustor blowout limits.

CONCLUDING REMARKS

In the recent experimental study of a premixing prevaporizing burner, a NO_x emission index as low as 0.3 was obtained with propane fuel at an inlet temperature of 800 K and an equivalence ratio of 0.4 (ref. 4). However, to attain this goal with liquid fuel, new designs of fuel injection systems that provide good premixing and prevaporizing are needed. The improvement in uniformity of fuel distribution makes it appear that the splash-groove injector would be useful for injecting liquid fuel into a premixing

prevaporizing fuel injection system. In this application, the present splash-groove injector would require modifications to optimize fuel jet diameters and other variables which influence fuel spreading in a vaporizing injector.

SUMMARY OF RESULTS

Exhaust emission characteristics of a high-pressure combustor segment using two designs of a splash-groove air-atomizing fuel injector and a pressure-atomizing simplex fuel nozzle were compared by burning both Jet A and diesel number 2 fuels. Exhaust smoke number and emission indices for oxides of nitrogen, carbon monoxide, and unburned hydrocarbons were determined for comparison. Also, combustor blowout conditions were determined for diesel number 2 and Jet A fuels. Test conditions included fuel-air ratios of 0.008 to 0.018, inlet-air temperatures and pressures of 477 to 811 K and 41 to 203 newtons per square centimeter, respectively, and a reference velocity of 21.3 meters per second.

Comparison of splash-groove injectors with splash-cone nozzles using Jet A fuel gave the following results:

1. Although injector model A (having 0.076-cm-diam orifices) did not give a reduction in carbon monoxide, unburned hydrocarbons, or smoke, it did give a reduction in the oxides-of-nitrogen emission index of approximately 25 percent, from 20 to 15, at 700 K, 203 newtons per square centimeter, and an 0.018 fuel-air ratio.

2. Injector model B (having 0.051-cm-diam orifices) did not reduce oxides of nitrogen, but it gave a reduction in the smoke number of approximately 45 percent, from 20 to 11, at 700 K, 101 newtons per square centimeter, and an 0.018 fuel-air ratio.

3. Injector model B gave a reduction of approximately 20 and 30 percent in carbon monoxide and unburned hydrocarbons, respectively, at 477 K, 40 newtons per square centimeter, and an 0.008 fuel-air ratio, and markedly reduced the combustor blowout limits.

Comparison of splash-groove injector model B with pressure-atomizing nozzles using diesel number 2 fuel gave the following results:

1. The oxides-of-nitrogen emission index was reduced from 21 to 17, or approximately 19 percent, with injector model B, at 700 K, 203 newtons per square centimeter, and an 0.018 fuel-air ratio.

2. Injector model B decreased the smoke number by approximately 28 percent, from 28 to 20, at 700 K, 101 newtons per square centimeter, and an 0.018 fuel-air ratio.

3. Injector model B gave reductions of approximately 75 and 50 percent in carbon monoxide and unburned hydrocarbons, respectively, at 477 K, 41 newtons per square centimeter, and an 0.008 fuel-air ratio.

Comparison of the performance of diesel number 2 and Jet A fuels with splash-groove injector model B gave the following results:

1. The oxides-of-nitrogen emission index for diesel number 2 fuel, at 700 K and an 0.018 fuel-air ratio, was higher at 41 newtons per square centimeter, about the same at 101 newtons per square centimeter, and lower at 203 newtons per square centimeter.

2. Carbon monoxide emissions were approximately the same, but emissions of unburned hydrocarbons and smoke number were approximately twice as high for diesel number 2 fuel.

3. Combustor blowout limits were approximately the same for diesel number 2 and Jet A fuels.

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, April 25, 1975,

505-03.

APPENDIX A

TEST FACILITY, TEST COMBUSTOR, AND INSTRUMENTATION

Test Facility

The combustor segment was mounted in the closed-duct test facility shown in figure 1. Combustion air drawn from the laboratory high-pressure supply system was indirectly heated to 811 K in a counterflow U-tube heat exchanger at combustor inlet-air pressures up to 203 newtons per square centimeter. The temperature of the air flowing out of the heat exchanger was automatically controlled by mixing the heated air with varying amounts of bypassed air. The test facility is described in more detail in reference 5.

Test Combustor

The test combustor, shown in figure 2, was a rectangular segment which simulated an annular combustor. The overall combustor length of 45.6 centimeters included a diffuser length of 14.0 centimeters and a burner length of 31.6 centimeters, consisting of a primary-zone length of 7.6 centimeters and a secondary-zone length of 24.0 centimeters. The combustor cross section was 5.3 by 30.5 centimeters at the diffuser inlet and 5.1 by 30.5 centimeters at the combustor exit. The maximum cross section was 15.3 by 30.5 centimeters. The inlet snout open area was 40 percent of the combustor inlet area. A detailed description of the airflow in the primary and secondary mixing zones is given in the discussion of combustor model 3 in reference 5.

Instrumentation

Combustor instrumentation stations are shown schematically in figure 2, and detailed locations are given in reference 5. Inlet-air total temperature was measured at station 1 in the diffuser inlet with eight Chromel-Alumel thermocouples. Inlet-air pressure was measured at the same location with four stationary rakes consisting of three total-pressure tubes connected to differential-pressure strain-gage transducers balanced by wall static-pressure taps located at the top and bottom of the duct. Combustor exhaust temperatures and pressures and smoke samples were obtained with a traversing probe mounted at the combustor exit, station 2. The probe consisted of 12 elements: five aspirating platinum-platinum-13-percent-rhodium total-temperature thermocouples, five total-pressure tubes, and two wedge-shape static-pressure tubes. Smoke

samples were withdrawn through the aspirating thermocouple lines. A detailed description of the probe is given in reference 5. The incremental travel and dwell time of the probe were controlled by automatic adjustable counters. Combustor exit temperatures and pressures were measured every 1.27 centimeters of travel for 23 locations across the combustor exhaust.

Sharp-edge orifices installed according to ASME specifications were used to measure airflow rates. Jet A fuel-flow rates were measured with pairs of turbine flowmeters connected in series to cross-check their accuracy. Three pairs of flowmeters were required to cover the flow range.

APPENDIX B

PROCEDURES FOR MEASURING EXHAUST EMISSIONS

Gaseous-Exhaust-Emission Measurement

Exhaust gas samples were obtained according to the procedure recommended in reference 6. Exhaust gases were withdrawn through the air-cooled stationary probe mounted approximately 92 centimeters downstream of the traversing probe and in the center of the exhaust gas stream (fig. 1). Concentrations of oxides of nitrogen, carbon monoxide, and unburned hydrocarbons were determined with the gas-analysis equipment described in reference 2. The gas sample temperature was maintained at approximately 423 K in the electrically heated sampling line. Most of the gas sample entered the analyzer oven, while excess flow was bypassed to the exhaust system. To prevent fuel accumulation in the sample line, a nitrogen purge was used just before and during combustor ignition.

After passing through the analyzer oven, the gas sample was divided into three parts, and each was analyzed. Concentrations of oxides of nitrogen, carbon monoxide, and unburned hydrocarbons were measured by the chemiluminescence, nondispersed-infrared, and flame-ionization methods, respectively. Gas samples used to determine oxides of nitrogen and carbon monoxide were passed through a refrigerated dryer and analyzed on a dry basis. Readings for oxides of nitrogen and carbon monoxide were corrected so that they could be reported on a wet basis, as were those for unburned hydrocarbons.

Carbon dioxide concentrations in the gas samples were determined, and fuel-air ratios calculated from a carbon balance agreed to within 15 percent with values obtained from fuel-flow- and airflow-rate measurements. Thus, representative exhaust-gas samples were obtained with the stationary probe, and emission values agreed with average values obtained with the traversing probe at the combustor exit.

Smoke Number Measurement

Smoke samples were obtained according to the procedure recommended in reference 7 by withdrawing exhaust gases through the probe while it traversed the combustor exit (fig. 1). The sample flow rate at standard conditions was 236 cubic centimeters per second. Smoke numbers determined with the smoke meter described in reference 2 were based on 1.623 grams of gas per square centimeter of filter tape. A reflective densitometer was used to measure comparative reflectance of the smoke stain, and a Welch Gray Scale was used for instrument calibration.

The smoke number, as defined in reference 7, was determined from the following expression:

$$\text{smoke number} = 100 (1 - r)$$

where r is the ratio of the percent of absolute reflectivity of the smoke stain to that of the clean filter paper.

Units

The U.S. customary system of units was used in primary measurements. Values were converted to SI units (Système International D'Unités) for reporting purposes only. When the conversions were made, consideration was given to implied accuracy, so that some of the values expressed in SI units were rounded off.

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TABLE I. - PHYSICAL AND CHEMICAL

PROPERTIES OF TEST FUELS

Property	Fuel	
	Jet A	Diesel number 2
Boiling point, K ($^{\circ}$ R)		
Initial	442 (796)	450 (810)
Final	544 (980)	607 (1094)
Distillation point (10 percent), K ($^{\circ}$ R)	460 (829)	490 (882)
Lower heating value, J/g (Btu/lb)	43 000 (18 600)	42 600 (18 464)
Hydrogen-carbon ratio	0.160	0.150
Aromatics, vol. %	16.8	30.5
Viscosity, m^2/sec (cS)		
At 294 K (70 $^{\circ}$ F)	1.3×10^{-6} (1.3)	4.0×10^{-6} (4.0)
At 239 K (-30 $^{\circ}$ F)	9.2×10^{-6} (9.2)	-----

TABLE II. - FUEL NOZZLE FLOW RATE VARIATION

WITH PRESSURE DROP

Fuel nozzle	Fuel	Flow rate		Fuel pressure drop, N/cm^2
		kg/sec	(lb/hr)	
Splash-groove, model A	Jet A	0.0152	120	9
		.0568	450	129
Splash-groove, model B	Jet A	0.0152	120	7
		.0568	450	95
Splash-groove, model B	Diesel number 2	0.0152	120	12
		.0568	450	154
Pressure-atomizing	Diesel number 2	0.0152	120	42
		.0568	450	560

TABLE III. - COMBUSTOR

TEST CONDITIONS

Inlet-air total pressure, N/cm^2	Inlet-air total temperature	
	K	$^{\circ}$ R
41	^a 477	^a 860
	589	1060
	700	1260
	811	1460
101	589	1060
	700	1260
203	589	1060
	^b 700	^b 1260

^aSimulated engine idle condition, 0.008 fuel-air ratio.

^bSimulated engine takeoff condition, 0.018 fuel-air ratio.

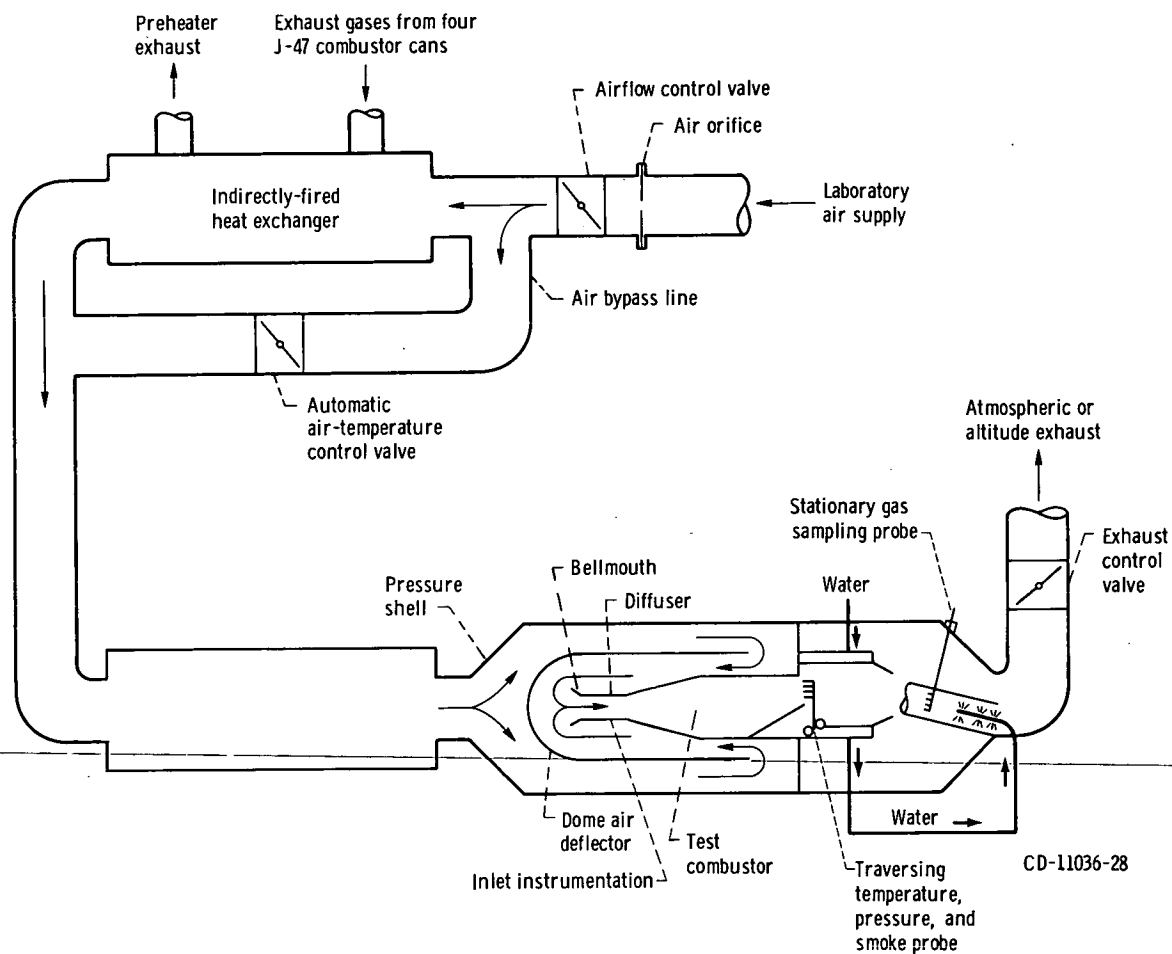


Figure 1. - Test facility and auxiliary equipment.

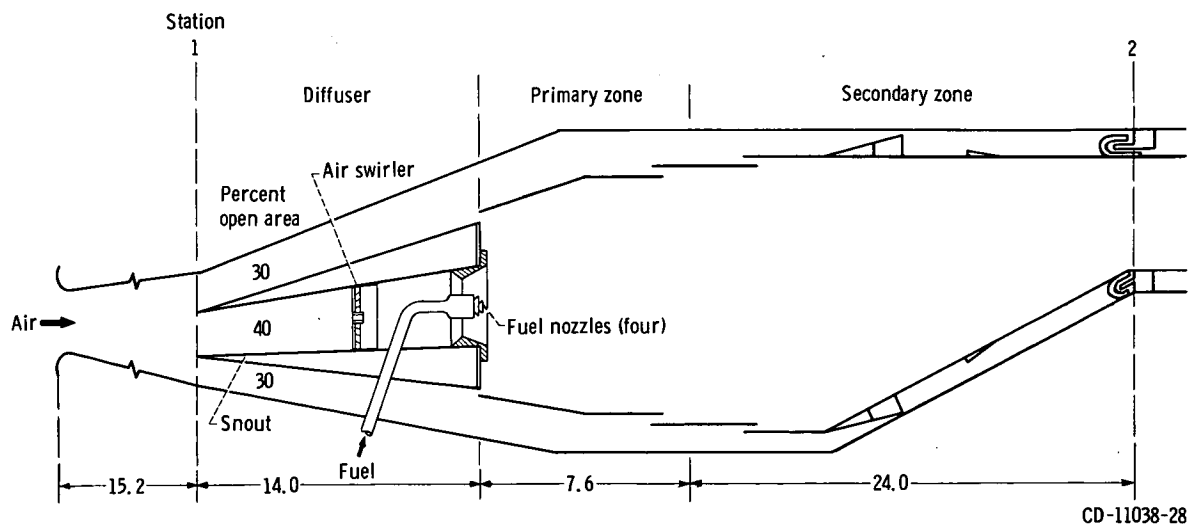
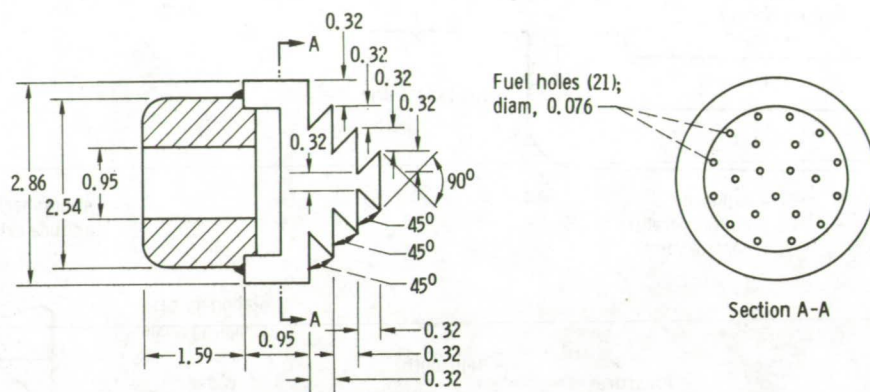
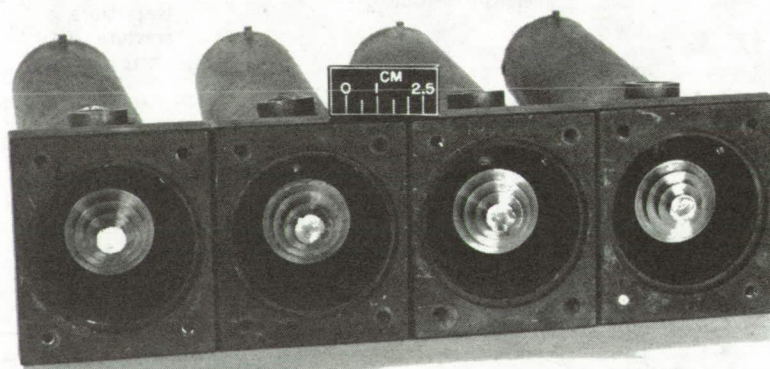


Figure 2. - Test combustor. (Dimensions are in centimeters.)



(a) Schematic diagram of model A. (Dimensions are in centimeters.)



(b) Injectors mounted in combustor snouts.

Figure 3. - Splash-groove fuel injectors.

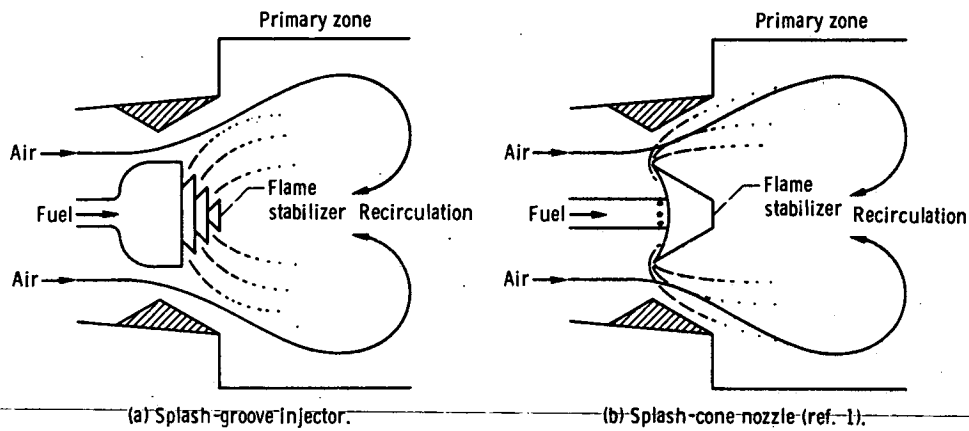
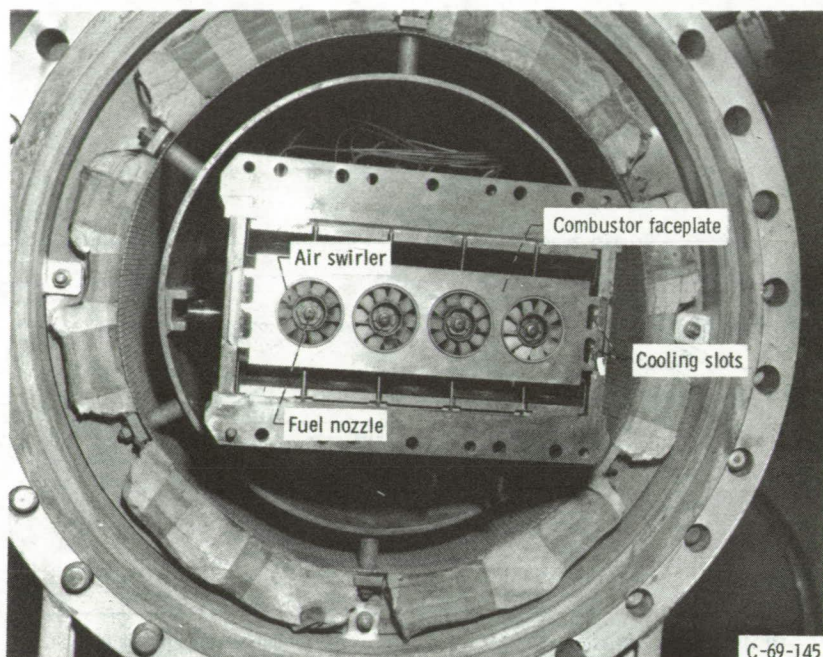
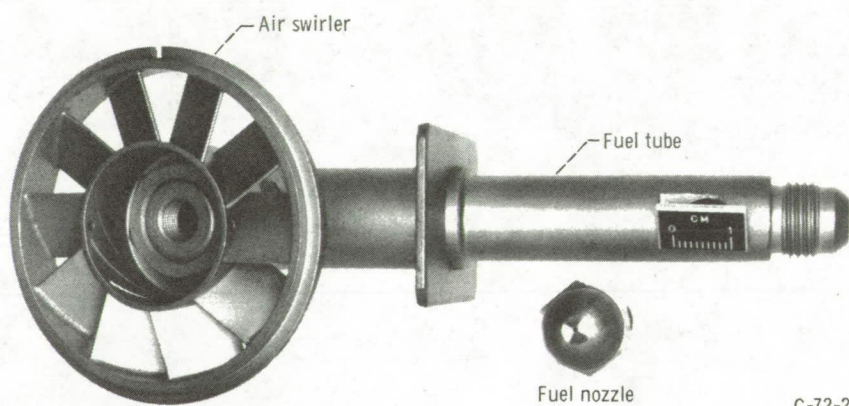


Figure 4. - Primary-zone flow models for air-atomizing fuel injectors.

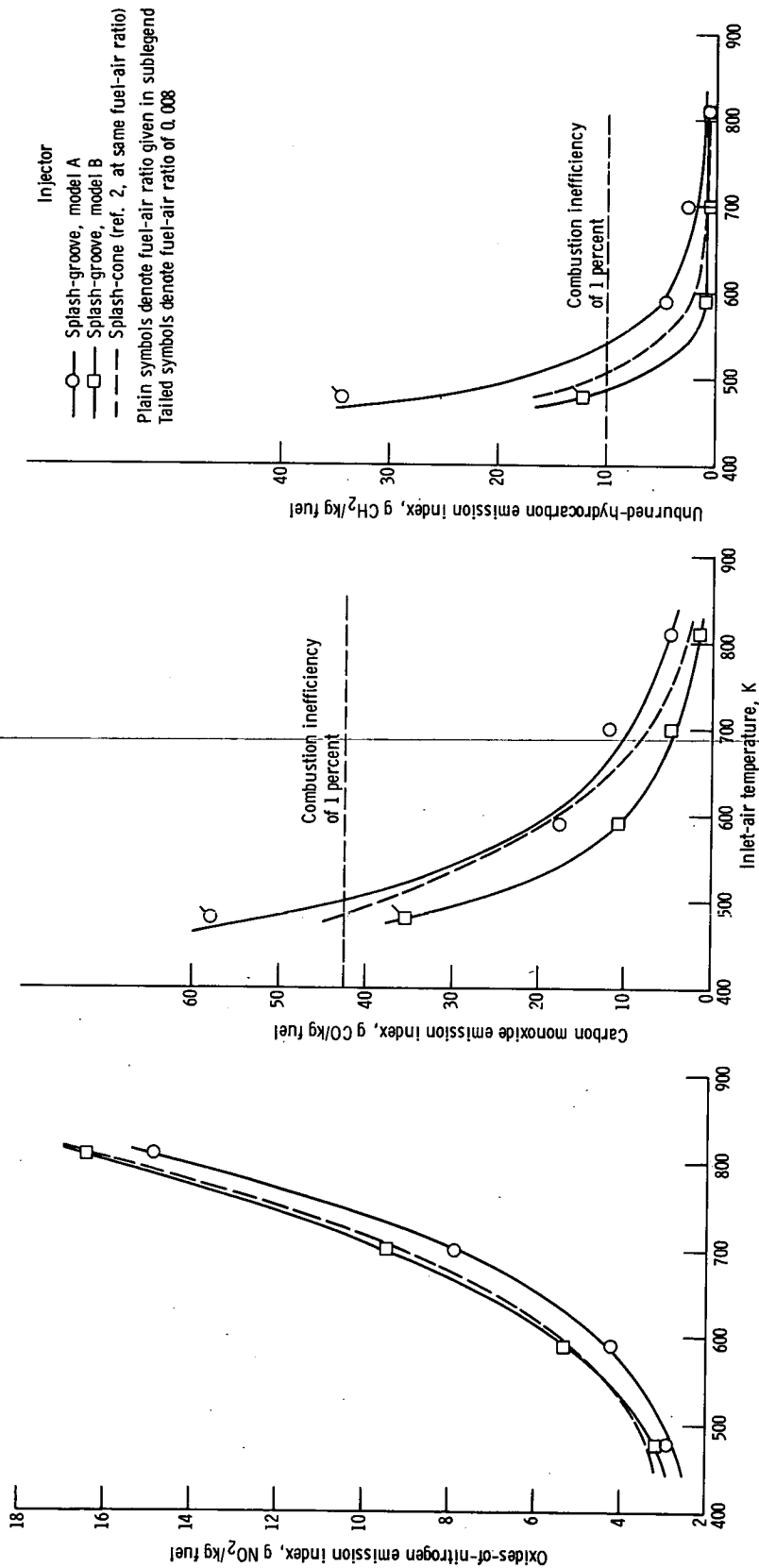


(a) Combustor primary-zone inlet (looking upstream).



(b) Fuel nozzle, air swirler, and fuel tube.

Figure 5. - Simplex pressure-atomizing nozzles.



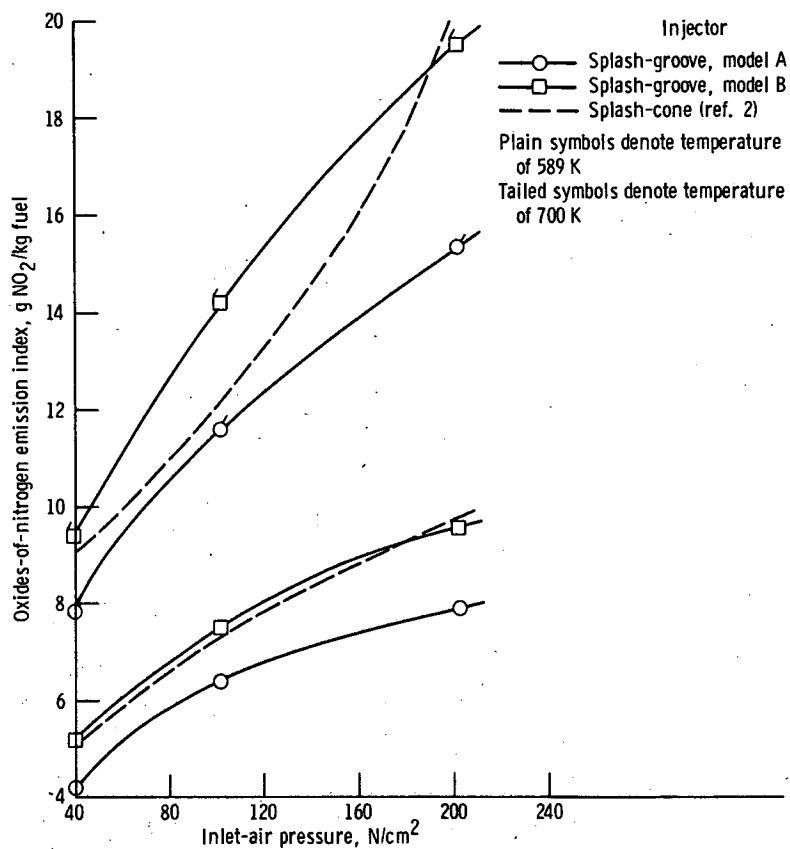


Figure 7. - Variation of oxides-of-nitrogen emission index with inlet-air pressure for jet A fuel. Fuel-air ratio, 0.018; reference velocity, 21.3 meters per second.

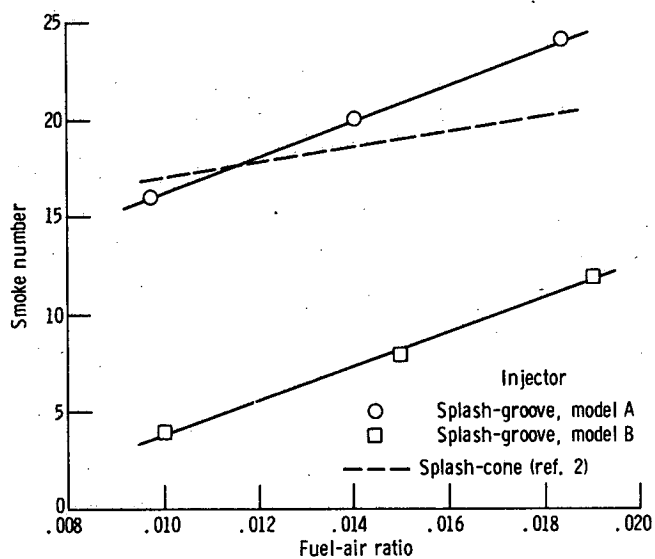
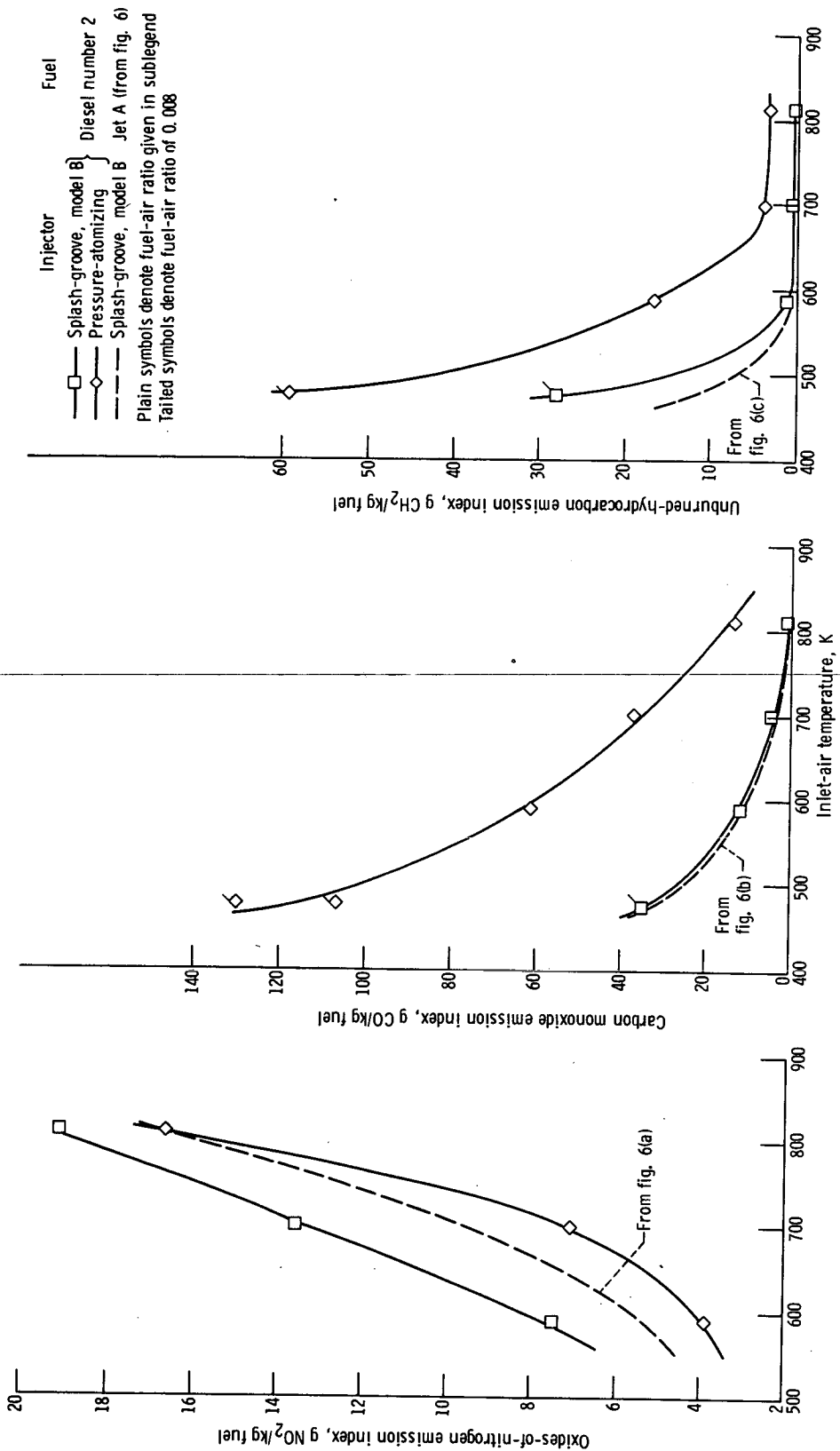


Figure 8. - Variation of exhaust smoke number with fuel-air ratio for jet A fuel. Inlet-air temperature, 700 K; inlet-air pressure, 101 newtons per square centimeter; reference velocity, 21.3 meters per second.



(a) Oxides-of-nitrogen; fuel-air ratio, 0.018.
 (b) Carbon monoxide; fuel-air ratio, 0.010.
 (c) Unburned hydrocarbons; fuel-air ratio, 0.010.
 Figure 9. - Variation of exhaust emission indices with inlet-air temperature for diesel number 2 fuel. Inlet-air pressure, 41 newtons per square centimeter; reference velocity, 21.3 meters per second.

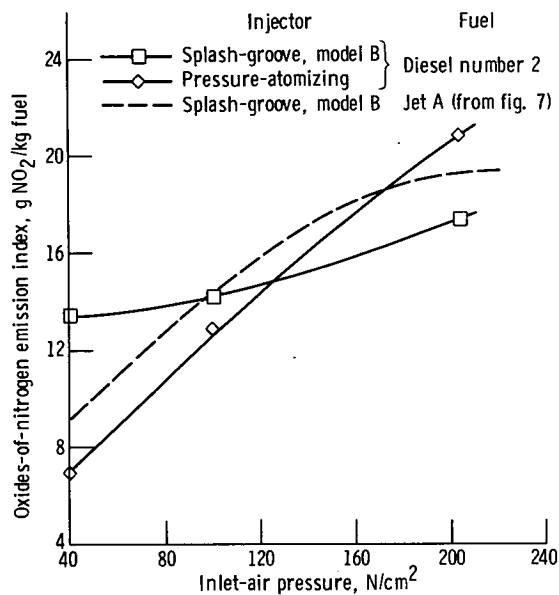


Figure 10. - Variation of oxides-of-nitrogen emission index with inlet-air pressure for diesel number 2 fuel. Fuel-air ratio, 0.018; inlet-air temperature, 700 K; reference velocity, 21.3 meters per second.

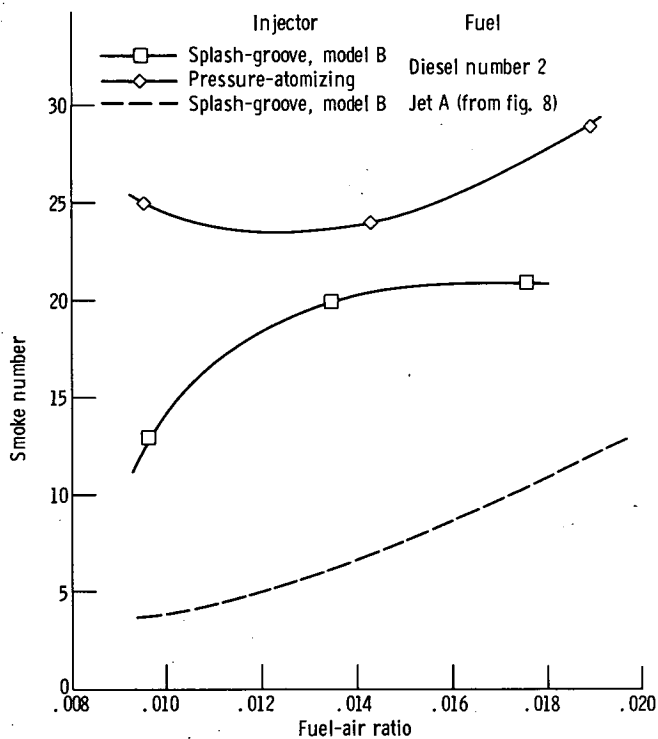


Figure 11. - Variation of exhaust smoke number with fuel-air ratio for diesel number 2 fuel. Inlet-air temperature, 700 K; inlet-air pressure, 101 newtons per square centimeter; reference velocity, 21.3 meters per second.

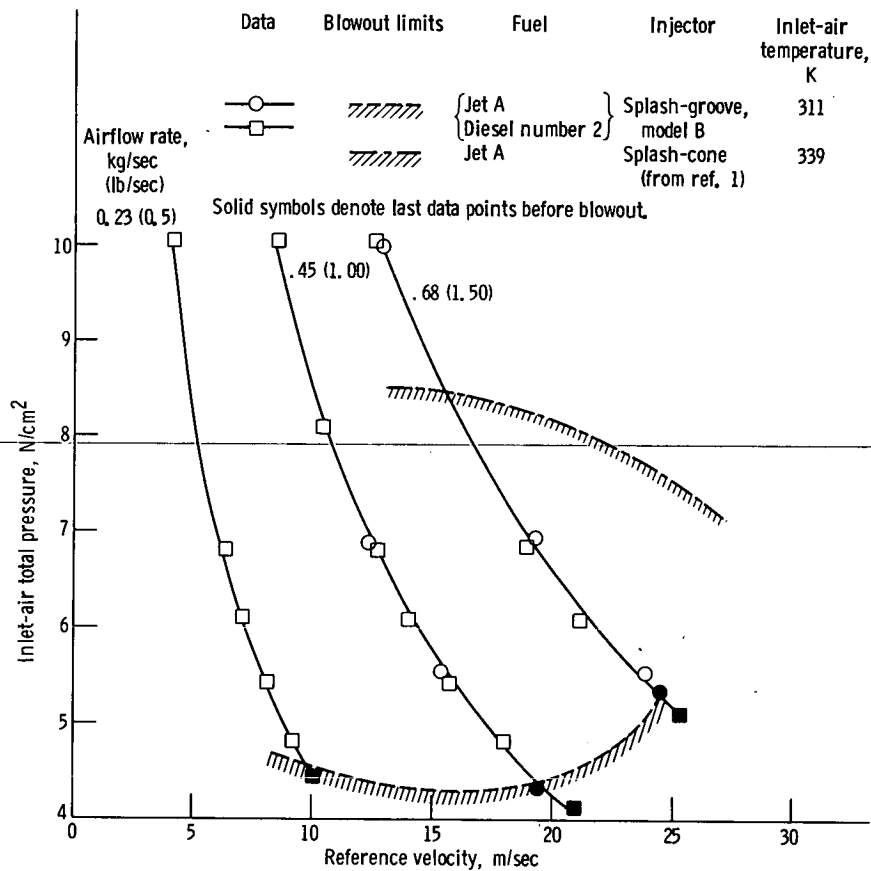


Figure 12. - Comparison of combustor blowout conditions for jet A and diesel number 2 fuels with splash-groove injector model B. Fuel-air ratio, 0.020.



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